NASA Technical Memorandum 103847

Transcapillary Fluid Shifts in Head and Neck Tissues During and After Simulated Microgravity

S. E. Parazynski, A. R. Hargens, B. Tucker,
M. Aratow, J. Styf, and A. Crenshaw

April 1991

National Aeronautics and
Space Administration

NASA Technical Memorandum 103847

Transcapillary Fluid Shifts in Head and Neck Tissues During and After Simulated Microgravity

S. E. Parazynski, A. R. Hargens, B. Tucker, M. Aratow, J. Styf, and A. Crenshaw
Ames Research Center, Moffett Field, California

April 1991

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

TRANSCAPILLARY FLUID SHIFTS IN HEAD AND NECK TISSUES DURING AND AFTER SIMULATED MICROGRAVITY

S. E. Parazynski,* A. R. Hargens, B. Tucker, M. Aratow, J. Styf, and A. Crenshaw

Ames Research Center

ABSTRACT

To understand the mechanism, magnitude, and time course of facial puffiness that occurs in microgravity, seven male subjects were tilted 6° head down for 8 hr, and all four Starling transcapillary pressures were directly measured before, during, and after tilt. Head-down tilt (HDT) caused facial edema and a significant elevation of microvascular pressures measured in the lower lip: capillary pressures increased from 27.7 ± 5 mm Hg pre-HDT to 33.9 ± 1.7 mm Hg by the end of tilt. Subcutaneous and intramuscular interstitial fluid pressures in the neck also increased as a result of HDT, while interstitial fluid colloid osmotic pressures remained unchanged. Plasma colloid osmotic pressures dropped significantly after 4 hr of HDT (21.5 ± 1.5 mm Hg pre-HDT to 18.2 ± 1.9 mm Hg at 4 hr HDT), suggesting a transition from fluid filtration to absorption in capillary beds between the heart and feet during HDT. After 4 hr of seated recovery from HDT, microvascular (capillary and venule) pressures remained significantly elevated by 5 to 8 mm Hg above baseline values, despite a significant HDT diuresis and the orthostatic challenge of an upright, seated posture. During the control (baseline) period, urine output was 46.7 ml/hr; during HDT it was 126.5 ml/hr. These results indicate that facial edema resulting from HDT is primarily caused by elevated capillary pressures and decreased plasma colloid osmotic pressures. Elevation of cephalic capillary pressures sustained for 4 hr after HDT suggests that there is a compensatory vasodilation to maintain microvascular perfusion. The negativity of interstitial fluid pressures above heart level also has implications for the maintenance of tissue fluid balance in upright posture.

INTRODUCTION

Qualitative and quantitative evidence indicates that the transition from Earth's 1-g environment to the microgravity of space induces a cephalad fluid shift within the human body, with resultant facial puffiness, nasal congestion, headache, and a marked decrease in calf circumference (refs. 3 and 5). Moore and Thornton (ref. 18) detected an 11.6% volume loss from the lower extremities in Space Shuttle astronauts; most of the fluid shifted to thoracic and cephalic portions of the body within the first 6–10 hr of flight. With the loss of a gravitational pressure gradient in microgravity, both

*Physician consultant: NASA Ames Research Center, Mountain View, CA. Emergency Medicine Resident: Denver General Hospital, Denver, CO.

intravascular and extravascular fluid from dependent areas (lower extremities) may shift passively cephalad, but the mechanism is poorly understood (ref. 10).

Some microgravity-induced responses in humans can be simulated using head-down tilt (HDT) bed rest (refs. 4, 8, 13, and 15). With ultrasound measurements, Kirsch and coworkers (ref. 16) documented that HDT increased the thickness of forehead tissues. Nixon and coworkers (ref. 20) found that HDT induces an acute shift of 900 cc of fluid, probably pooled venous blood, from both legs after only 30 min of bed rest. Hargens and colleagues (ref. 13) then documented a decrease in interstitial fluid pressures in the legs of subjects exposed to 8 hr of HDT that resulted in lower-extremity tissue dehydration. Following reentry to 1 g after lengthy flights, cosmonauts often have leg pain which may be caused by venous pooling in the lower extremities (ref. 30). In a study by Moore and Thornton (ref. 18), most of the volume that shifted away from the legs during spaceflight had returned by 1.5 hr postflight.

Levick and Michel (ref. 17) measured intracapillary pressures in the human toe of 80–90 mm Hg during upright standing, as opposed to about 30 mm Hg while the feet were at heart level. Presumably, intracapillary pressures above heart level are lower and less variable with positional changes than those in the feet because heart-to-head distance is shorter than heart-to-foot distance. Consequently, the microvasculature of the head and neck may be less adapted to increases in vascular pressure associated with HDT (refs. 1 and 25) and microgravity. This may account for the sequellae of acute HDT and early spaceflight (facial puffiness, nasal congestion, headache). The initial abrupt transition to microgravity or HDT causes a venous blood redistribution toward the head, probably resulting in higher arterial and capillary pressures in the head and neck. Normal interstitial fluid pressures in the intramuscular and subcutaneous tissues above the heart are unknown, as are the initial changes during simulated microgravity.

The purpose of this study was to quantitate changes in the four Starling transcapillary fluid pressures in the head and neck that occur during acute exposure to 6° HDT, in order to understand the mechanism of edema associated with this posture. We also evaluated the degree and time course of the footward fluid shift that occurs after return from 6° HDT to an upright posture.

This research was supported by a grant from NASA (199-14-12-04). Scott Parazynski was supported by a NASA Graduate Student Fellowship and the Stanford Medical Scholars Program.

METHODS

Experimental Design

Measurements of the Starling transcapillary fluid pressures during a control period, 8 hr of HDT, and 4 hr of seated recovery allow determination of net fluid pressure across the capillary wall before, during, and after simulated microgravity. Transcapillary fluid shifts are primarily governed by hydrostatic and colloid osmotic pressures, as indicated in the Starling–Landis equation (refs. 6, 7, 11, and 26):

$$J = LS[(P_c - P_t) - \sigma_c(\pi_c - \pi_t)]$$

where

J	transcapillary fluid movement
L	hydraulic conductance
S	surface area
P_c	capillary blood pressure
P_t	interstitial fluid pressure
σ_c	capillary membrane reflection coefficient
π_c	capillary blood colloid osmotic pressure
π_t	interstitial fluid colloid osmotic pressure

Subjects

Seven male subjects, of mean age 33.7 ± 4.0 yr, mean weight 75.2 ± 3.2 kg, and mean height 174.9 ± 3.4 cm, participated in an 8-hr, 6° HDT bed-rest exposure in the Human Research Facility at NASA Ames Research Center. The protocol was approved by the Human Research Experiments Review Board at NASA Ames and the Human Subjects Committee at Stanford Medical Center, Stanford, California. All subjects were fully briefed about the risks involved. A medical history and physical examination were obtained before the study; all subjects were in excellent overall health and were taking no medications.

Protocol

Direct measurements of neck and lip transcapillary fluid pressures allowed quantitation of forces that cause fluid shifts above the heart during acute simulated microgravity. Physiologic parameters (heart rate, blood pressure) were followed before HDT, throughout the period of HDT, and during recovery. Subjects were instructed to maintain their regular diet *ad libitum* and record all fluid and food intake, and urine output, for 24 hr before HDT. Urinary volume was measured in a graduated cylinder at the time of voiding. Water ad libitum and a liquid diet (Sustacal, Mead Johnson, Evansville, IN) containing 2400-3000 kcal/day, not adjusted for body size or energy expenditure, were provided during the experiment day. Fluid intake and urine output volumes were recorded throughout the control period, 8 hr of HDT, and 4 hr of recovery.

Subjects were asked to arise at 6 a.m. the day of the study, and to stand or sit upright until arrival at the research facility. Baseline measurements were obtained during the hour before HDT. At approximately 9 a.m., the subjects were transferred supine to a gurney and then tilted to 6° HDT. They remained in this position for the next 8 hr. At approximately 5 p.m. the subjects were moved to a chair, and they remained in a seated position for the 4-hr recovery period. Pulse and blood pressure were measured every two hr and after the position change.

Interstitial fluid pressures in the neck were measured while subjects were seated upright, after 4 and 8 hr of HDT, and after 4 hr of seated recovery. Antecubital venous blood samples (5 cc) for

measurement of colloid osmotic pressures were obtained at the same times. Capillary and venular pressures were measured in the superficial lip mucosa before HDT; after 30 min, 4 hr, and 8 hr of HDT; and after 4 hr of recovery.

Techniques

Interstitial fluid pressure (P_t) was monitored regularly in the sternocleidomastoid muscle and the overlying subcutaneous tissue with two indwelling Myopress catheters (ref. 27) (fig. 1). The catheters were inserted under local anesthesia (1 cc of 1% Lidocaine), under sterile conditions, and subsequently connected to a low-volume-displacement pressure transducer (Electromedics model MS-20). Occasionally, catheter patency was checked for possible clotting by microinfusion (0.003 ml) of normal saline. Plasma colloid osmotic pressure (π_c) was measured from blood samples collected by venipuncture, using a colloid osmometer (ref. 2) (accuracy ±1 mm Hg) that has a membrane with molecular weight retention of 30,000 Daltons (Amicon PM-30). Interstitial fluid colloid osmotic pressure (π_t) of neck subcutis was determined using an implanted nylon thread (ref. 22). Sternocleidomastoid muscle π_t was determined using an empty wick catheter (ref. 11). Blood pressures and pulse rates were measured using a commercial sphygmomanometer and stethoscope.

Because capillaries accessible to micropuncture are unavailable in the neck, the servo-nulling technique for measuring microvascular pressures (ref. 31) was adapted for micropuncture of lip capillaries, enabling direct readings of intracapillary pressure, using methods previously performed in the vascular beds of animals (ref. 14). Each volunteer was placed with his or her head resting on a custom-designed platform that minimized vibration. Specially prepared micropipets were inserted into lip vessels with a Leitz micromanipulator under 40X magnification (fig. 2). A fiber-optic light source was used to illuminate the field. Uniform micropipets were prepared with a pipet puller from custom 0.9-mm borosilicate capillary tubing (Drummond Glass) with 0.2-mm wall thickness. The pipets were placed on a Crysalan grinding wheel and ground to a 25°–30° beveled tip with an outer diameter of 1–3 μm. Micropuncture was performed in the lower lip under a drop of normal saline while the lip was lightly secured with soft tissue clamps at the lateral aspects of the mouth. This arrangement maintained unobstructed arterial flow to and venous return from the region, which could be observed under the microscope. A small thermistor was applied to monitor the temperature of the lip. Several capillary and venule pressure readings were made at each time interval, and subjects reported no discomfort or pain from this procedure.

The difference in height from the lower lip to the heart was measured to determine the hydrostatic pressure gradient between lip capillaries and the heart during upright seated and HDT positions. During the HDT period, the lip was at the same horizontal level as the left ventricle of the heart, and thus the hydrostatic pressure gradient was zero. With subjects seated upright, their heads in the micropuncture headrest, a carpenter's level was placed horizontally at the level of the lower lip. A second level was placed perpendicular to this, originating from a point intersecting the midsternum. The distance between the sternum and the horizontal level was used to estimate the hydrostatic pressure between the lip capillary beds and the heart during seated posture before and after HDT.

Data Analysis

Time points used in the statistical analysis study were pre-HDT (baseline), 4 hr of HDT, 8 hr of HDT, and 4 hr after HDT. Two-tailed paired t-tests were used to evaluate differences in weight, urine output, fluid intake, and cardiovascular parameters. For intramuscular fluid pressures and plasma colloid osmotic pressures, a repeated-measures ANOVA was used to determine significant differences from baseline values. Post-hoc tests were subsequently performed if significance was found. A one-way ANOVA between the pre-HDT value and each time point was used to determine significant changes in mean arterial pressure, systolic blood pressure, diastolic blood pressure, capillary pressure, venule pressure, subcutaneous and muscle interstitial fluid pressures, subcutaneous colloid osmotic pressure, and intramuscular colloid osmotic pressure. $P < 0.05$ was considered significant.

RESULTS

All seven subjects experienced facial puffiness and reported nasal congestion and headache during HDT. Six of the subjects tolerated the invasive procedures without pain or sequellae. One subject, who was recovering from an influenza infection, had a vasovagal reaction prior to HDT, and the investigation was immediately stopped. This subject participated in the complete protocol two weeks later with no problems. There was a significant ($p < 0.05$) weight loss (1.01 ± 0.33 kg for the group) during the experiment day coincident with a negative fluid balance (table 1). The hourly urine output increased ($p < 0.05$) although fluid intake did not change during HDT.

Cardiovascular parameters showed compensatory trends with HDT, but most of these differences were not statistically significant (table 2). However, mean heart rate decreased significantly ($p < 0.05$) with the onset of HDT, and then stabilized near pre-HDT baseline values during the remainder of HDT. Mean heart rate during recovery was significantly elevated ($p < 0.02$) compared to that during initial HDT. Systolic blood pressure dropped significantly, by 10 mm Hg, after the change from HDT to upright seated posture during recovery. Diastolic blood pressure remained unchanged throughout the study.

Intracapillary pressure recordings were obtained from the lip mucosa, with excellent reproducibility between repeated punctures of the same vessel ($\pm$ 4.4 mm Hg). Measurements were taken from chart recorder tracings when a clear arterial pulse wave pattern was present, ranging from 4–90 sec in duration. Lip and ambient air temperatures were essentially unchanged over time, with means of 35.5° C and 24.0° C, respectively. Mean capillary pressure, P_c, increased ($p < 0.05$) from a baseline value of 27.7 ± 1.5 mm Hg (range 17.9 – 39.1) to 33.9 ± 1.7 mm Hg (range 21.2 – 51.9) at the end of HDT (fig. 3). This increase in P_c was sustained throughout 8 hr of HDT, and, interestingly, was still elevated after 4 hr of seated recovery.

Postcapillary venule pressures followed a similar trend, with a more gradual increase from baseline (15.1 ± 1.3 mm Hg), that reached statistical significance by 4 hr of HDT (21.6 ± 1.5 mm Hg) (fig. 4). Like the capillary pressures, venule pressures remained significantly

elevated above their pre-HDT baseline value after 4 hr of recovery to upright posture (23.5 ± 2.5 mm Hg).

There was a twofold difference between positional changes in the vertical distance between the heart and lip (for HDT and upright) and that for lip capillary pressures. Whereas the measured increase in hydrostatic pressure (determined from distance between heart and lip) was 11.4 mm Hg, mean P_c from upright to HDT increased (significantly) by only 6.2 mm Hg at 8 hr of HDT.

Interstitial fluid pressures from the sternocleidomastoid muscle and overlying subcutaneous tissue were negative in the control period and tended to increase (not significantly) with HDT (fig. 5). After HDT, however, the P_t values dropped significantly to below-baseline negative values, possibly as a result of interstitial dehydration secondary to the increased urinary output and reinstitution of upright blood pressure gradients.

Plasma colloid osmotic pressure dropped significantly from 21.5 ± 1.5 mm Hg to 18.2 ± 1.9 mm Hg by 4 hr of HDT; there was then a gradual restorative trend toward the baseline level (fig. 6). No significant changes in intramuscular (fig. 7) or subcutaneous (fig. 8) fluid colloid osmotic pressures were detected in the neck.

DISCUSSION

HDT Model of Microgravity

The HDT model of microgravity is well documented for reproducing the facial puffiness, nasal congestion, headache, and decrease in calf size associated with microgravity (refs. 4, 8, 13, and 15). A significant weight loss and diuresis (see table 1) in all of our subjects associated with *ad libitum* water and liquid food intake suggest that a new fluid equilibrium is established during HDT. Urine output was significantly greater than fluid intake during HDT, which suggests that there was a decrease in intravascular volume during HDT. Diuresis has not been documented for microgravity, however, possibly because astronauts maintain a horizontal posture with knees up prior to launch (ref. 19). Systolic blood pressure tends to increase abruptly during the initial challenge of HDT; this increase correlates well with actual spaceflight data obtained for a rhesus monkey (ref. 24). This stimulus to the carotid baroreceptors may cause a fluid volume overload that induces diuresis. We observed decreases in heart rate and diastolic blood pressure after transfer of the subjects from the seated position to HDT. Tomaselli and coworkers (ref. 29) report a slight downward trend in cardiac output and stroke volume during the first hour of HDT, which suggests that thoracic fluid volume may increase acutely during HDT. Our post-tilt recovery hemodynamic indices suggest that there is a drop in circulating plasma volume, along with decreases in systolic and diastolic blood pressures and a relative increase in heart rate.

Starling Pressures During HDT

Capillary and venule pressures increased by 8–10 mm Hg as a result of HDT, and peaked at the end of the 8 hr of tilt. The initial measurements during HDT showed strikingly different patterns, however. Capillary pressure increased after 30 min of HDT, reaching a maximum at 4 hr HDT. In contrast, venule pressure was only marginally increased early in HDT. It is possible that initially a postcapillary vasoconstriction occurred, which would explain the lower venule pressures at the onset of HDT. By the completion of HDT, however, venule pressures had increased significantly; cephalad edema formation may indicate that the ability of postcapillary vasodilation to regulate the fluid shift has been exceeded. Surprisingly, 4 hr post-tilt, capillary and venule pressures remained substantially above baseline values, despite a documented diuresis and slight decrease in blood pressure post-tilt. Possible mechanisms for this phenomenon include a compensatory cephalic vasodilation within 4 hr after resumption of seated posture, facilitating cerebral perfusion in the fluid-depleted state. Another possibility is a postcapillary vasoconstriction, to maintain the elevated intracapillary pressures of HDT in the presence of the decreased intravascular volume and arterial pressure that may exist in the post-HDT recovery period.

Subcutaneous and intramuscular fluid pressures increased during HDT, but not significantly. This increase is in qualitative agreement with results from a study of an animal model of microgravity, in which an increase in interstitial fluid pressure of neck subcutis occurred after 48 hr of tail suspension in rats (ref. 12). Fluid extravasating into the interstitium during HDT follows a biphasic pressure–volume compliance relationship, described by Guyton and coworkers (ref. 9). Because of the high compliance of the subcutaneous and muscular tissues in the initial positive range of P_t, a large volume of fluid can be accommodated with little increase in P_t. Pre-HDT P_t values were negative, which may indicate that P_t above the heart is normally negative during upright posture. Fluid volume added during tilt was absorbed on the most compliant portion of the pressure–volume curve (see ref. 9). However, with reduced plasma volume and general tissue dehydration, P_t dropped significantly to below pre-HDT levels along the steep portion of the compliance curve. Post-HDT (recovery) P_t values were significantly below pre-HDT (baseline) levels, presumably because of the diuresis noted during HDT and the reinstitution of the blood pressure gradients from the head to the feet that exist with upright posture.

The finding that the plasma colloid osmotic pressure dropped significantly by 4 hr of HDT suggests a change from a generalized filtration mode to an absorption mode in the capillary beds below the heart during HDT. This reversal may induce fluid resorption from the lower-body interstitium, and a resultant dilution of plasma proteins. The diuretic effect that we obtained returns plasma colloid osmotic pressure toward baseline later during HDT and during recovery.

Subcutaneous and intramuscular colloid osmotic pressures did not change significantly with HDT. Results from Noddeland (ref. 21), also, indicate that body posture has little effect on tissue colloid osmotic pressures. Therefore, the cephalic edema that forms during HDT probably results from both fluid and proteins filtering across cephalic capillary beds; capillaries above heart level may be relatively more permeable to protein or have a lower capillary membrane reflection coefficient (σ_c) than dependent tissues. Histomorphometric analyses of both human and giraffe capillaries (ref. 32) show that capillary basement membrane thickness increases from head to legs in adults, whereas there is little difference in children and fetuses. Therefore, it is possible that σ_c in head and

neck tissues may be less than the 0.9 that is estimated for leg tissues by other investigators (refs. 23 and 28).

Net flux across the capillary membrane can be determined using the Starling-Landis equation (see table 3). Assuming, for simplicity, that $\sigma_c = 0.9$, there is a net movement of fluid out of the capillaries in both skeletal muscle and subcutaneous tissue, and lymphatic drainage normally prevents edema formation in the pre-HDT upright posture. During HDT, however, there is a substantially larger net pressure gradient for fluid transport out of the capillaries of the head and neck. Presumably the lymphatic system is at or near full capacity (ref. 7) during such HDT exposure, and cephalic edema ensues. There is a confirmed net filtration pressure gradient out of the capillaries after 4 hr of recovery. The absolute values of +30.2 mm Hg in skeletal muscle and +26.2 mm Hg in subcutis reflect persistent P_c elevation and P_t depression secondary to dehydration.

We believe we are the first group to measure all four Starling-Landis transcapillary pressures in humans directly. This study may also be the first to measure directly intracapillary pressures and interstitial fluid pressures above heart level in humans. We suggest that the cephalic edema that occurs during HDT may be a result of (1) an increase in P_c in the head during HDT posture, associated with the loss of the head-to-heart blood pressure gradient, and (2) a decrease in plasma colloid osmotic pressure during HDT. A third and important factor is the increase during HDT of microcirculatory flow in tissues of the head, where precapillary control of bloodflow is significantly less well developed than in the feet (ref. 1). Further studies in this area may aid in development of countermeasures to the adverse consequences of microgravity.

REFERENCES

1. Aratow, M.; Hargens, A. R.; Meyer, J.-U.; and Arnaud, S. B.: Postural Responses of Head and Foot Cutaneous Microvascular Flow and the Influence of Bedrest on These Responses. Aviat. Space Environ. Med., vol. 62, 1991, pp. 246-251.

2. Aukland, K.; and Johnson, H.: Colloid Osmometer for Small Fluid Samples. Acta Physiol. Scand., vol. 90, 1974, pp. 485-490.

3. Berry, C. A.; Catterson, A. D.; Coons, D. O.; and Kelly, G. F.: Man's Response to Long-Duration Flight in Gemini Spacecraft. Gemini Midprogram Conference, Including Experiment Results. NASA SP-121, 1966, pp. 235-261.

4. Convertino, V. A.; Bisson, R.; Bates, R.; Goldwater, D.; and Sandler, H.: Effects of Antiorthostatic Bedrest on the Cardiorespiratory Responses to Exercise. Aviat. Space Environ. Med., vol. 52, 1981, pp. 251-255.

5. Dietlein, L. F.: Skylab: A Beginning. Biomedical Results from Skylab. NASA SP-377, 1977, pp. 408-418.

6. Gore, R. W.; and McDonough, P. F.: Fluid Exchange Across Single Capillaries. Annu. Rev. Physiol., vol. 42, 1980, pp. 337-357.

7. Granger, H. J.; Laine, G. A.; Barnes, G. E.; and Lewis, R. E.: Dynamics and Control of Transmicrovascular Fluid Exchange. Edema, N. C. Staub and A. E. Taylor, eds., Raven Press, 1984, pp. 189-228.

8. Greenleaf, J. E.; Silverstein, L.; Bliss, J.; Langenheim, V.; Rossow, H.; and Chao, C.: Physiological Responses to Prolonged Bed Rest and Fluid Immersion in Man: a Compendium of Research (1974-1980). NASA TM-81324, 1982, pp. 3-74.

9. Guyton, A. C.; Granger, H. J.; and Taylor, A. E.: Interstitial Fluid Pressure. Physiol. Rev., vol. 51, 1971, pp. 527-563.

10. Hargens, A. R.: Fluid Shifts in Vascular and Extravascular Spaces During and After Simulated Weightlessness. Med. Sci. Sports Exerc., vol. 15, 1983, pp. 421-427.

11. Hargens A. R.; Cologne, J. B.; Menninger, F. J.; Hogan, J. S.; Tucker, B. J.; and Peters, R. M.: Normal Transcapillary Pressures in Human Skeletal Muscle and Subcutaneous Tissues. Microvasc. Res., vol. 22, 1981, pp. 177-189.

12. Hargens, A. R.; Streskal, J.; Johansson, C.; and Tipton, C. M.: Tissue Fluid Shift, Forelimb Loading, and Tail Tension in Tail-Suspended Rats. Physiologist, vol. 27, 1984, pp. S37-S38.

13. Hargens, A. R.; Tipton, C. M.; Gollnick, P. D.; Mubarak, S. J.; Tucker, B. J.; and Akeson, W. H.: Fluid Shifts and Muscle Function in Humans During Acute Simulated Weightlessness. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol., vol. 54, 1983, pp. 1003-1009.

14. Intaglietta, M.; Pawula, R. F.; and Tompkins, W. R.: Pressure Measurements in the Mammalian Microvasculature. Microvasc. Res., vol. 2, 1970, pp. 212-220.

15. Kakurin, L. I.; Lobachik, V. I.; Mikhailov, V. M.; and Senkevich, Y. A.: Antiorthostatic Hypokinesia as a Method of Weightlessness Simulation. Aviat. Space Environ. Med., vol. 47, 1976, pp. 1083-1085.

16. Kirsch, K.; Röcker, L.; and Wicke, H. J.; Methodological Aspects of Future Cardiovascular Research in Space. Physiologist, vol. 20, 1979, pp. S11-S14.

17. Levick, J. R.; and Michel, C. C.: The Effects of Position and Skin Temperature on the Capillary Pressures in the Fingers and Toes. J. Physiol., vol. 274, 1978, pp. 97-109.

18. Moore, T. P.; and Thornton, W. E.: Space Shuttle Inflight and Postflight Fluid Shifts Measured by Leg Volume Changes. Aviat. Space Environ. Med., vol. 58, no. 9, Suppl., 1987, pp. A91-A96.

19. Nicogossian, A. E.; Huntoon, C. L.; and Pool, S. L.: Space Physiology and Medicine. Lea & Febinger, 1989.

20. Nixon, J. V.; Murray, R. G.; Bryant, C.; Johnson, Jr., R. L.; Mitchell, J. H.; Holland, O. B.; Gomez-Sanchez, C.; Vergne-Marini, P.; and Blomqvist, C. G.: Early Cardiovascular Adaptation to Simulated Zero Gravity. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol., vol. 46, 1979, pp. 541-548.

21. Noddeland, H.: Influence of Body Posture on Transcapillary Pressures in Human Subcutaneous Tissue. Scand. J. Clin. Lab. Invest., vol. 42, 1982, pp. 131-138.

22. Noddeland, H.; Hargens, A. R.; Reed, R. K.; and Aukland, K.: Interstitial Colloid Osmotic and Hydrostatic Pressures in Subcutaneous Tissue of Human Thorax. Microvasc. Res., vol. 24, 1982, pp. 104-113.

23. Renkin, E. M.; Watson, P. D.; Sloop, C. H.; Joyner, W. M.; and Curry, F. E.: Transport Pathways for Fluid and Large Molecules in Microvascular Endothelium of the Dog's Paw. Microvasc. Res., vol. 14, 1977, pp. 205-214.

24. Sandler, H.; Krotov, V. P.; Hines, J.; Magadev, V. S.; Benjamin, B. A.; Badekeva, A. M.; Halpryn, B. M.; Stone, H. L.; and Krilov, V. S.: Cardiovascular Results from a Rhesus Monkey Flown Aboard the Cosmos Flight 1514 Spaceflight. Aviat. Space Environ. Med., vol. 58, 1987, pp. 529-536.

25. Sfakianos, P. H.; Hargens, A. R.; and Akeson, W. H.: Microvascular Flow Adjustments with Postural Changes in Humans. Physiologist, vol. 28, 1985, pp. S175-S176.

26. Starling, E. H.: On the Absorption of Fluids from the Connective Tissue Space. J. Physiol., vol. 19, 1896, pp. 312-326.

27. Styf, J. R.; and Körner, L. M.: Microcapillary Infusion Technique for Measurement of Intramuscular Pressure During Exercise. Clin. Orthop. Rel. Res., vol. 207, 1986, pp. 253-262.

28. Taylor, A. E.; Granger, D. N.; and Brace, R. A.: Analysis of Lymphatic Protein Flux Data. I. Estimation of the Reflection Coefficient and Permeability Surface Area Product for Total Protein. Microvasc. Res., vol. 13, 1977, pp. 297-313.

29. Tomaselli, C. M.; Kenney, R. A.; Frey, M. A. B.; and Hoffler, G. W.: Cardiovascular Dynamics During the Initial Period of Head-Down Tilt. Aviat. Space Environ. Med., vol. 58, 1987, pp. 3-8.

30. Vorob'yev, Y. I.; Yegorov, A. D.; Kakurin, L. I.; and Nefedov, Y. G.: Medical Support and Principal Results of Examination of the "Soyuz-9" Spacecraft Crew. Kosmicheskaya Biologiyai Meditsina, vol. 4, no. 6, 1970, pp. 26-31, translated in Space Biol. Med., vol. 4, no. 6, 1970, pp. 34-41.

31. Wiederhielm, C. A.; Woodbury, J. W.; Kirk, S.; and Rushmer, R. F.: Pulsatile Pressure in the Microcirculation of the Frog's Mesentery. Amer. J. Physiol., vol. 207, 1964, pp. 173-176.

32. Williamson, J. R.; Volger, N. J.; and Kilo, C.: Regional Variations in the Width of the Baseline Membrane of Muscle Capillaries in Man and Giraffe. Am. J. Pathol., vol. 63, 1971, pp. 359-370.

Table 1. Fluid balance before and during HDT. (mean ± SE)

Parameter	
Initial weight	75.2 ± 3.2 kg
Final weight	74.2 ± 3.0 kg
Change in weight	−1.01 ± 0.33 kg*
Intake/hr	70.9 ± 8.5 ml/hr
Control output/hr	46.7 ± 8.7 ml/hr
HDT input/hr	100.5 ± 21.5 ml/hr
HDT output/hr	126.5 ± 22.3 ml/hr**

*significant weight loss ($p < 0.05$).
**significantly higher than pre-HDT control period ($p < 0.05$).

Table 2. Cardiovascular parameters before, during, and after HDT. (mean ± SE)

Time	Heart rate, beats/min	Systolic blood pressure, mm Hg	Diastolic blood pressure, mm Hg
Pre-HDT	58.3 ± 3.7	119.3 ± 4.2	82.1 ± 3.9
Initial HDT	53.4 ± 1.8*	125.3 ± 5.3	75.9 ± 4.1
4 hr HDT	58.3 ± 2.0	126.7 ± 3.9	83.8 ± 2.3
8 hr HDT	61.6 ± 3.4	127.4 ± 4.0	83.0 ± 2.2
Initial post-tilt	63.3 ± 1.3**	117.0 ± 4.0†	78.7 ± 4.0
4 hr post-tilt	62.9 ± 1.6**	116.9 ± 4.2	79.6 ± 3.1

*Significantly less than pre-HDT control period ($p < 0.05$).
**Significantly higher than pre-HDT control period ($p < 0.02$).
†Significantly less than end of HDT ($p < 0.05$).

Table 3. Net transcapillary pressure gradient in the head and neck before, during, and after HDT

Net filtration out of capillaries when $\Delta P = (P_c - P_t) - \sigma_c (\pi_c - \pi_t) > 0$, assuming $\sigma_c = 0.9$				
Tissue	Pre-HDT	4 hr HDT	8 hr HDT	4 hr post-tilt
Skeletal muscle	+18.5	+26.7*	+24.1*	+30.2*
Subcutaneous tissue	+18.7	+27.4*	+27.4*	+26.2*

*Significantly higher than pre-HDT control values.

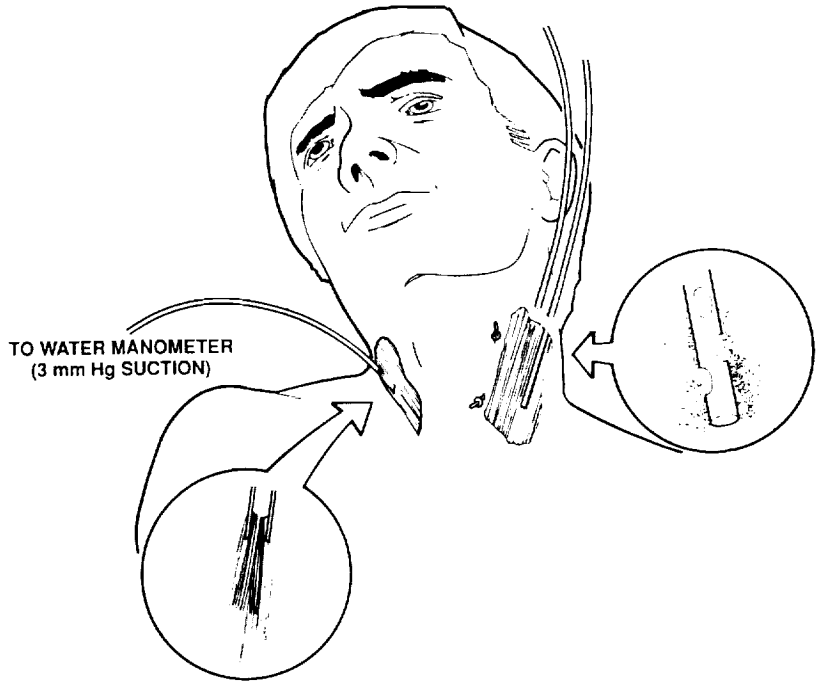

Figure 1. Two Myopress catheters (one shown enlarged) were inserted in the left sternocleidomastoid muscle and overlying subcutaneous tissue, connected via saline-filled high-pressure tubing to pressure transducers for measurement of P_t. An implanted wick on the left side of the subject's neck is used to collect subcutaneous fluid for subsequent determination of P_t. Similarly, an empty wick catheter (tip enlarged) is implanted into the right sternocleidomastoid muscle to collect intramuscular fluid for determination of P_t.

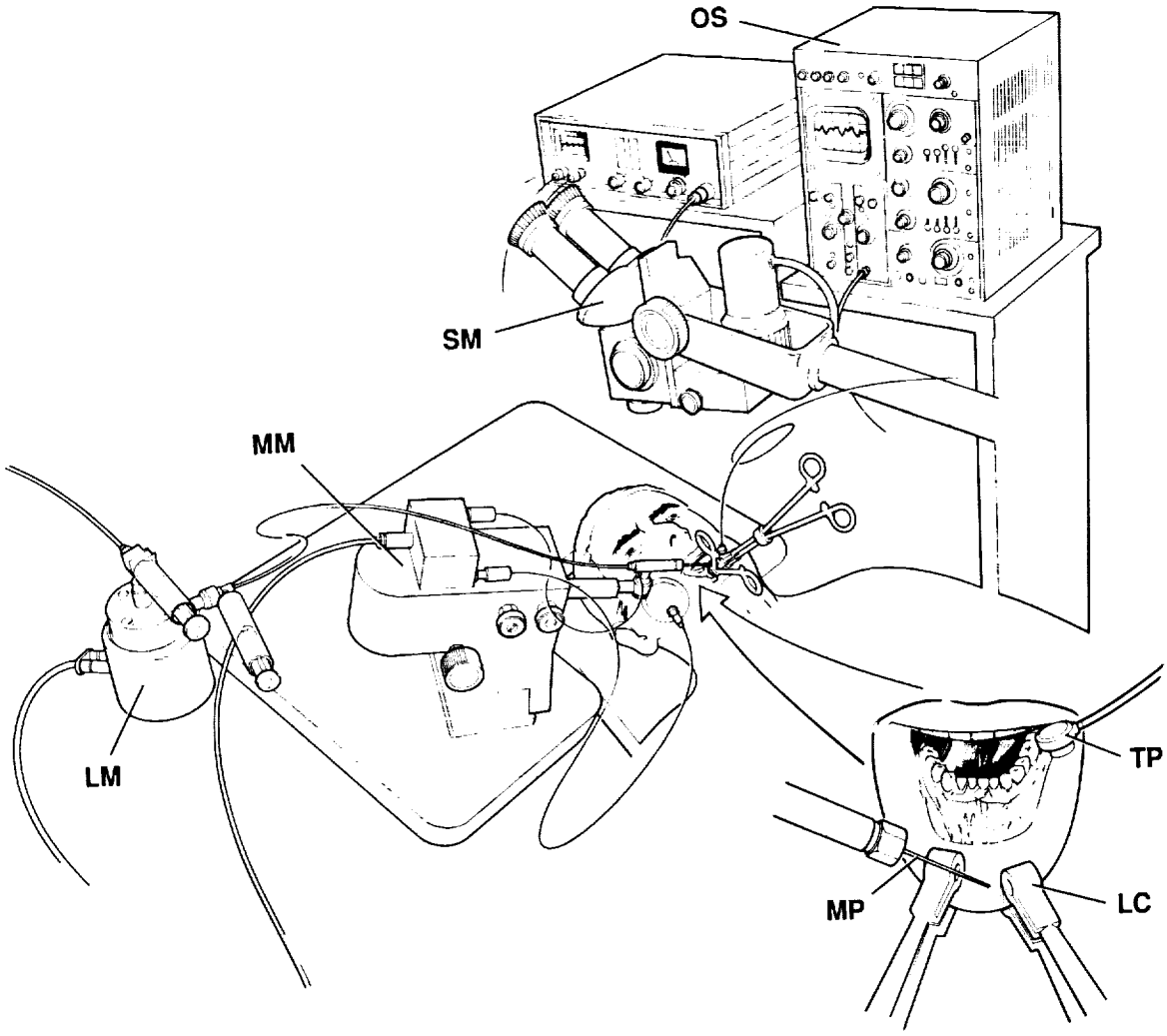

Figure 2. Intracapillary pressure recording system. Subjects were stabilized in a specially-designed headrest for micropuncture of lip capillaries and venules. An enlargement of the lip is shown below right. LM = linear-drive motor, MM = micromanipulator, SM = surgical microscope, OS = oscilloscope, MP = micropipet, LC = lip clamp, TP = thermistor probe.

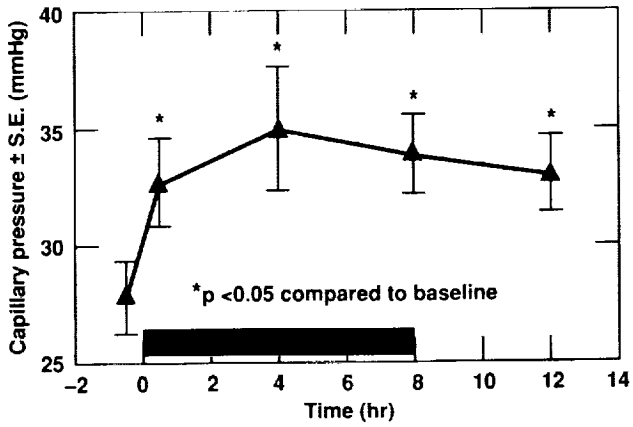

Figure 3. Effect of HDT on capillary blood pressure in the lip. Lower bar indicates period of HDT.

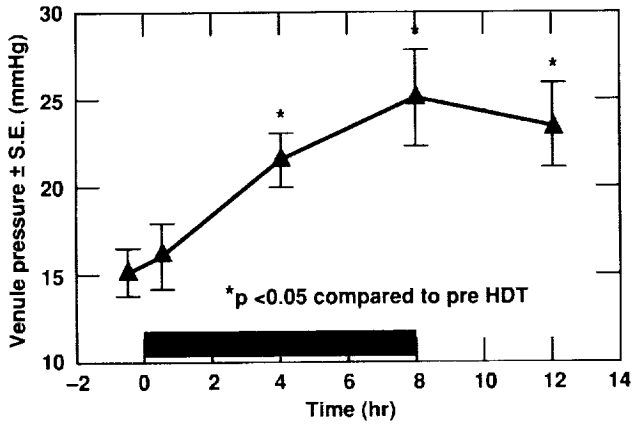

Figure 4. Effect of HDT on post-capillary venule blood pressure. Lower bar indicates period of HDT.

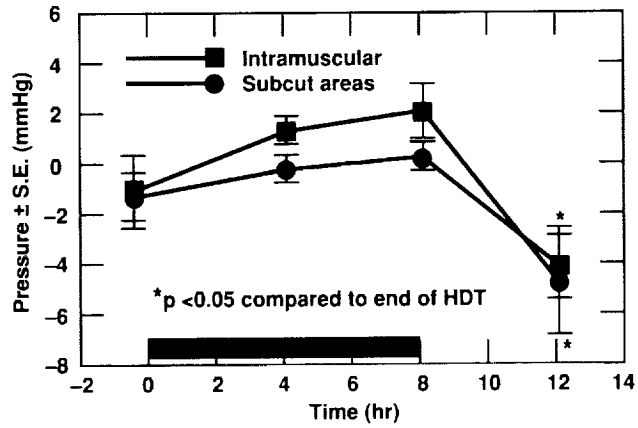

Figure 5. Effect of HDT on interstitial fluid pressures from the sternocleidomastoid muscle and overlying subcutis. Lower bar indicates period of HDT.

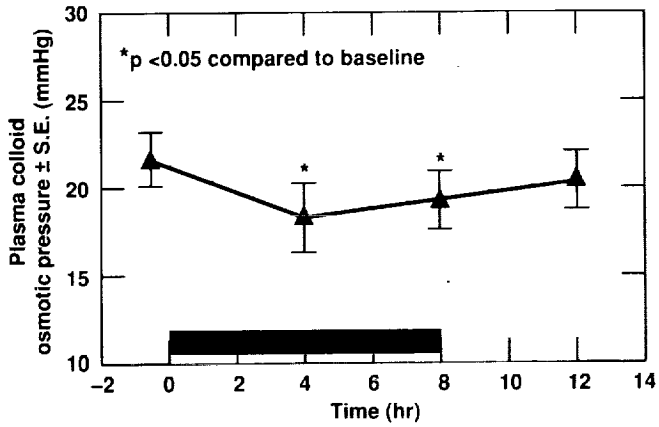

Figure 6. Effect of HDT on plasma colloid osmotic pressure, π_c. Lower bar indicates period of HDT.

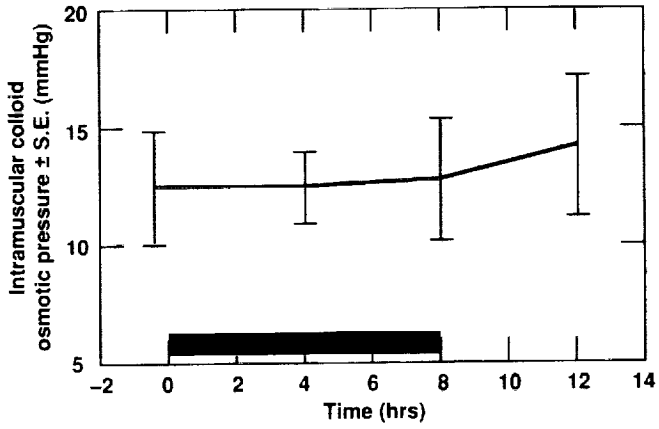

Figure 7. Effect of HDT on colloid osmotic pressure in neck muscle tissues. Lower bar indicates period of HDT.

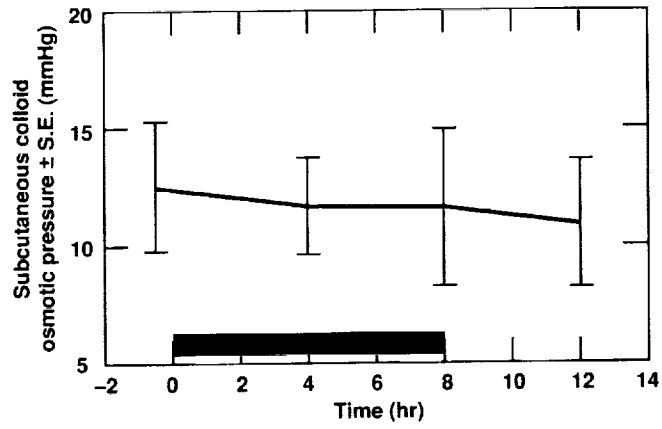

Figure 8. Effect of HDT on colloid osmotic pressure in neck subcutis. Lower bar indicates period of HDT.

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-103847		

4. Title and Subtitle	5. Report Date
Transcapillary Fluid Shifts in Head and Neck Tissues During and After Simulated Microgravity	April 1991
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
S. E. Parazynski, A. R. Hargens, B. Tucker, M. Aratow, J. Styf, and A. Crenshaw	A-91096
	10. Work Unit No. 199-14-12-04

9. Performing Organization Name and Address	11. Contract or Grant No.
Ames Research Center Moffett Field, CA 94035-1000	
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address	14. Sponsoring Agency Code
National Aeronautics and Space Administration Washington, DC 20546-0001	

15. Supplementary Notes

Point of Contact: Alan R. Hargens, Ames Research Center, MS 239-11, Moffett Field, CA 94035-1000
(415) 604-5746 or FTS 464-5746

16. Abstract

To understand the mechanism, magnitude, and time course of facial puffiness that occurs in microgravity, seven male subjects were tilted 6° head down for 8 hr, and all four Starling transcapillary pressures were directly measured before, during, and after tilt. Head-down tilt (HDT) caused facial edema and a significant elevation of microvascular pressures measured in the lower lip: capillary pressures increased from 27.7 ± 5 mm Hg pre-HDT to 33.9 ± 1.7 mm Hg by the end of tilt. Subcutaneous and intramuscular interstitial fluid pressures in the neck also increased as a result of HDT, while interstitial fluid colloid osmotic pressures remained unchanged. Plasma colloid osmotic pressures dropped significantly after 4 hr of HDT (21.5 ± 1.5 mm Hg pre-HDT to 18.2 ± 1.9 mm Hg at 4 hr HDT), suggesting a transition from fluid filtration to absorption in capillary beds between the heart and feet during HDT. After 4 hr of seated recovery from HDT, microvascular (capillary and venule) pressures remained significantly elevated by 5 to 8 mm Hg above baseline values, despite a significant HDT diuresis and the orthostatic challenge of an upright, seated posture. During the control (baseline) period, urine output was 46.7 ml/hr; during HDT it was 126.5 ml/hr. These results indicate that facial edema resulting from HDT is primarily caused by elevated capillary pressures and decreased plasma colloid osmotic pressures. Elevation of cephalic capillary pressures sustained for 4 hr after HDT suggests that there is a compensatory vasodilation to maintain microvascular perfusion. The negativity of interstitial fluid pressures above heart level also has implications for the maintenance of tissue fluid balance in upright posture.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Orthostasis, Edema, Transcapillary pressures, Head-down tilt, Interstitial fluid pressures, Colloid osmotic pressures	Unclassified-Unlimited Subject Category - 52

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	18	A02

NASA FORM 1626 OCT 86

For sale by the National Technical Information Service, Springfield, Virginia 22161